

(1) Patent specifications are addressed to one of ordinary skill in the art. Although patent examiners are not ones of ordinary skill in the art, "Office personnel must always remember to use the perspective of one of ordinary skill in the art. Claims and disclosures are not to be evaluated in a vacuum" MPEP §2106.

(2) Enclosed are pages 361–366 from *Digital Signal Processing in Telecommunications* by Kishan Shenoi, Prentice-Hall, 1995. As shown by the text, non-linear processing is part of an echo cancelling system and is the part that removes "residual" echo when other techniques have failed. Non-linear processors attenuate but **non-linearly**, as is clear from FIG. 6.15. As known to those of skill in the art, non-linear devices produce artifacts, which is why Genter needs filters 42a–p. See also column 7, lines 6–22.

(3) To one of ordinary skill in the art, non-linear processors and multiplex circuits are not remotely related.

It is therefore respectfully submitted that claims 1 and 11 fully distinguishes over the Genter patent.

The Examiner's comments concerning the McCaslin et al. patent are similarly inapposite. The echo suppresser disclosed in the McCaslin et al. patent must cope with echo tails of various duration. The McCaslin et al. patent describes a fast attack circuit and a slow attack circuit for coping with short or long echo tails. There is **always** an attenuation (high or low). **Nowhere** is it disclosed that a signal be attenuated if the duration of the signal exceeds a threshold.

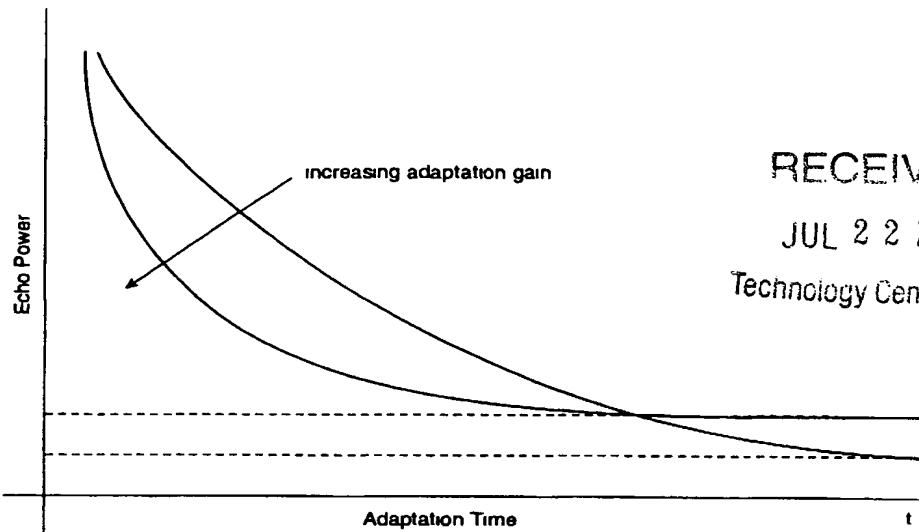
Claim 8 was not rejected and is presumed allowed.

In view of the foregoing remarks, it is respectfully submitted that claims 1, 2, and 5–12 are in condition for allowance and a Notice to that effect is respectfully requested.

Respectfully submitted,



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**Fig. 6.12**  
Indicating trade-off between adaptation rate and achievable ERL as a function of adaptation gain

**d) Performance.** The performance of an adaptive filter depends not just on the adaptation gains,  $\mu$ , but also on the filter length,  $N$ , and the signal-to-noise ratio. Provided the length is large enough to correct for the (generally infinite) length of the echo path impulse response, increasing  $N$  further is detrimental; doubling  $N$  will reduce the **ERLE** by 3 dB. The **ERLE** is also affected by the signal-to-noise ratio. An  $x$  dB decrease in **SNR** translates directly to an  $x$  dB reduction in the (expected) **ERLE**. While we did not analyze the impact of nonlinearities in the echo path, it is obvious that such behavior cannot be modeled by a linear time-invariant system and thus an adaptive **FIR** may not provide any echo-cancelation if the nonlinear behavior is pronounced. If the nonlinear effects are slight then they can be modeled as an additive noise that degrades the **ERLE** much the same way as locally generated signal.

#### 6.4 NETWORK ECHO CANCELERS

Echo cancelers are the preferred method of echo control in the modern network. The principal advantage is that echo cancelers over suppressors is that the former do not necessarily restrict the communication to a half-duplex mode. All echo cancelers used in the network are digital in nature and operate on digital signals. A detailed description of the requirements of an echo canceler are provided in CCITT Recommendation **G.165** [9].

The location of an echo canceler is on the **trunk side** of a switch since echo control is required only for interswitch calls. This is diagrammed in Fig. 6.13.

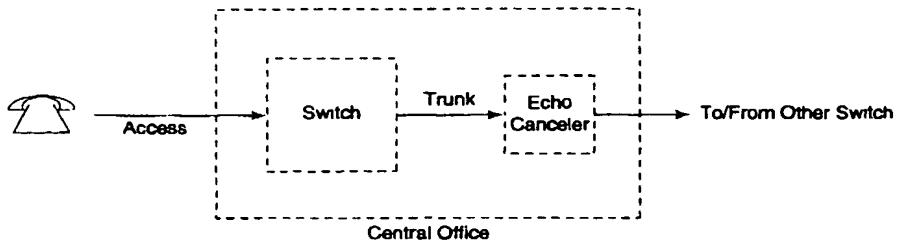


Fig. 6.13  
Echo cancelers are usually deployed on the trunk side of a switch

The trunk-side location implies that the interconnections to and from the echo canceler are DS1 or E1. DS1 and E1 represent Time Division Multiplexed (TDM) assemblies. As we described in Chapter 1, DS1 is comprised of 24 voice channels, each corresponding to an 8-kHz sampling rate,  $\mu$ -law encoded signal, plus some framing overhead to make up a serial bit-stream of  $(24*8*8 + 8) = 1544$  kbits/sec. E1 is comprised of 30 voice channels with overhead, each channel representing a signal sampled at 8 kHz and quantized according to the A-law for a net serial bit rate of  $(30*8*8 + 128) = 2048$  kbits/sec. It is important to recognize that since echo cancelers operate on an assembly of 24 channels it is possible to share computational power and amortize the cost of hardware over 24/30 channels.

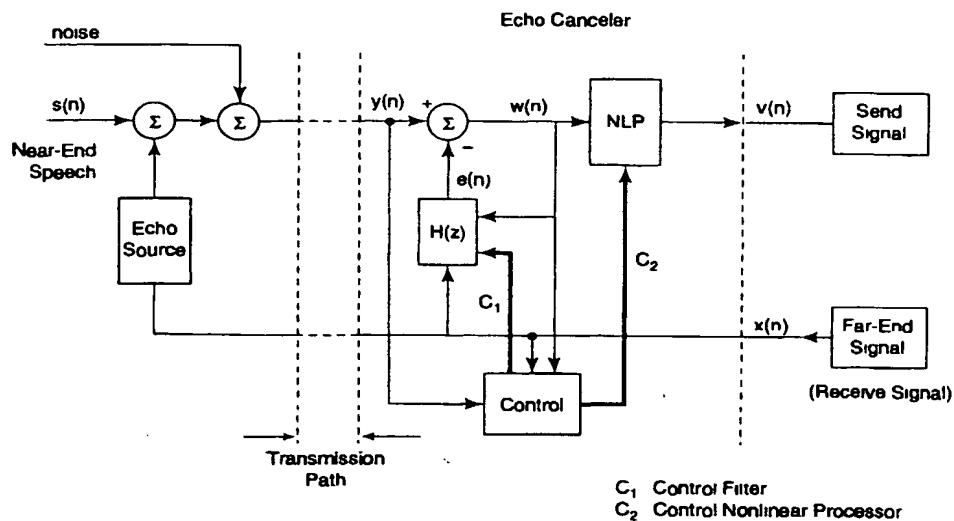
The reason for showing a telephone and access line is to indicate which side of the echo canceler the echo originates. This side is called, variously, the *near-end*, or *tailside*. Conversely, the other side of the canceler is referred to as the *long-haul*, *far-end*, or *network* side. Other terminologies are used in the literature but the meaning is usually obvious from the context. The speech signal originating from the near-end side is always considered *local*.

#### 6.4.1 Echo Canceler Functional Summary

A simplified block diagram indicating the functions of an echo canceler is shown in Fig. 6.14. The structure is called a "split-type echo canceler" since it removes echo only in one direction. All echo cancelers manufactured today are of the split type since it is expected that there will be an echo canceler at each side of the circuit, with the tails pointing in opposite directions, to remove echo generated from both "local" ends.

The signal  $\{x(n)\}$  from the far end, which can be observed by the canceler, is not modified in any way but passed on toward the near-end. This signal reaches the tail side hybrid and some fraction of the power is returned as echo. The block diagram also shows the injection of near-end speech and noise. These are important. The noise injected is a primarily quantization noise (and aliasing) introduced by the A/D converter but may have other sources as well. The signal from the tail side,  $\{y(n)\}$ ,

is thus a combination of near-end speech, noise, and echo. Since the physical location of the canceler may be far removed from the hybrid, the source of the echo, we have shown a transmission path with dotted lines. This transmission path may include various equipment including switches, cross-connects, and multiplexers, in addition to transmission media such as copper cable, fiber optic cable, radio, and so on. We shall assume that no signal processing, as far as the particular speech channel is concerned, is performed in the transmission path and thus it appears just as a delay

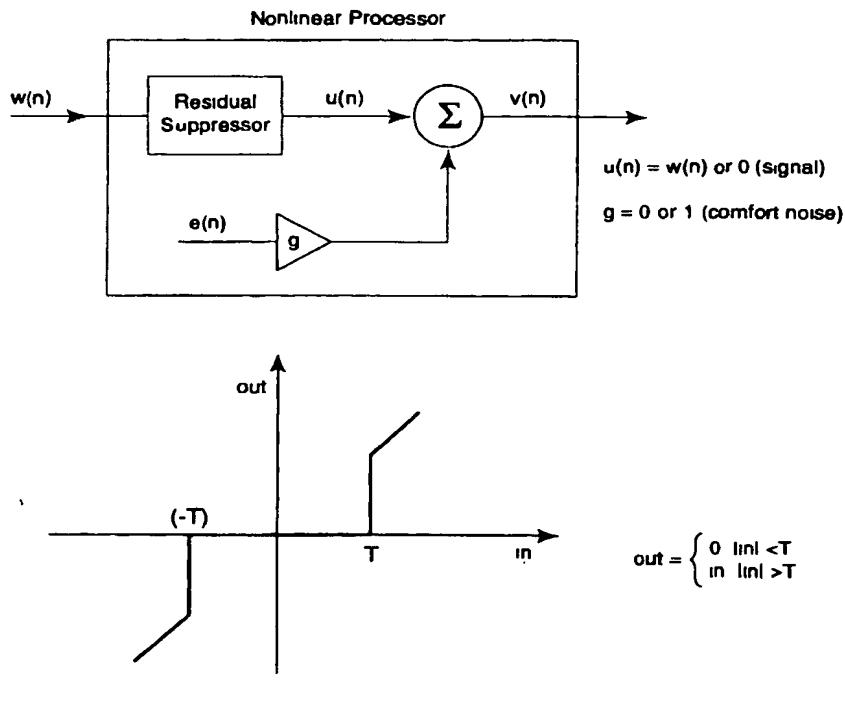


**Fig. 6.14**  
Principal components of an echo canceler are the control mechanism, adaptive filter, and nonlinear Processor

The canceler implements an adaptive filter, denoted by  $H(z)$ , that generates a local replica of the echo and subtracts this replica from  $\{y(n)\}$  to generate  $\{w(n)\}$  which, ideally, comprises just the near-end speech and, unfortunately, any locally generated noise in the tail circuit. The operation of the adaptive filter is described in Section 6.3, where we saw that  $w(n)$  is not completely echo-free. Consequently all echo cancelers include what is known as a **Nonlinear Processor (NLP)**, which is actually an echo suppressor, as depicted in Fig. 6.15, to remove the last vestiges of remaining echo. Thus the **Send** signal,  $\{v(n)\}$ , which is transmitted in the long-haul direction is, for the most part, echo free.

Also shown in the diagram is a block labeled **Control**. The functions of this block are to control the adaptive filter ( $C_1$ ) and the non-linear processor ( $C_2$ ). This is achieved by processing the various signals that can be observed by the block, namely  $\{x(n)\}$ ,  $\{y(n)\}$ , and  $\{w(n)\}$ . An additional function of the control block is to determine whether the echo canceler should be disabled for the duration of the call and to

determine when, if the canceler has been disabled, to re-enable the canceler. The notions of disabling and re-enabling are discussed in more detail later.



**Fig. 6.15**  
Nonlinear processor comprises a residual suppressor (center clipper) and means to inject comfort noise.

A simplified block diagram of an echo canceler in a DS1 environment is shown in Fig. 6.16. It comprises circuitry to perform the multiplexing and demultiplexing of the 24 constituent channels contained in the DS1 assembly. The adaptive filters are done on a per-channel basis, implying that there are logically 24 such units within the equipment. The block labeled **Control** includes the functions associated with the DS1 nature of the input-output signals and also includes the control functions associated with each of the 24 separate per-channel cancelers on a shared basis. A similar diagram can be generated for the E1 case where instead of 24 we have 30 channels.

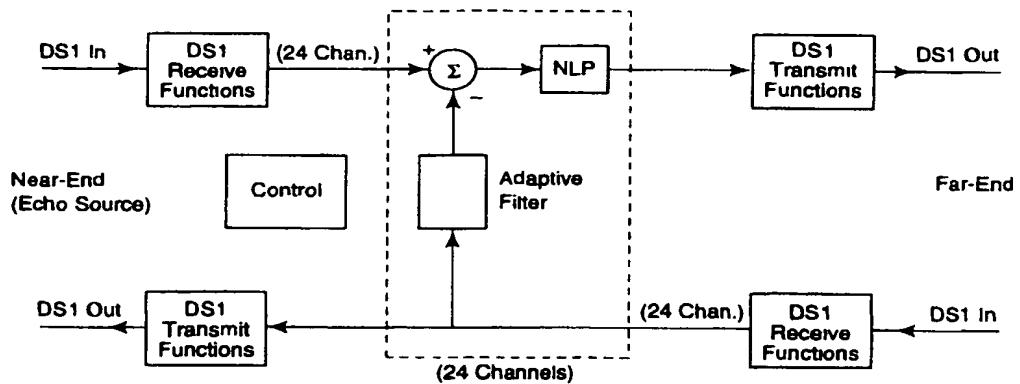


Fig. 6.16  
Block diagram of a DS1 level echo canceler

In discussing the operation of an echo canceler we introduce the term "state" of an echo canceler. Just as we saw for echo suppressors, the notion of the "state" of an echo canceler refers to the relative strengths of the far-end signal vis-à-vis the near-end signal. "Single-talk" is the condition in which the power of the reference signal,  $P_r$ , is much greater than the power of the near-end signal,  $P_n$ . "Hard double-talk" is the condition where  $P_r$  is much greater than  $P_n$  and is usually indicative that the far-end talker is silent and the near-end talker is active. "Double-talk" is the condition where  $P_r$  and  $P_n$  are approximately equal. "Soft double-talk" is the condition between single-talk and double-talk and reflects our concern of hangover times. The "idle" state is when  $P_r$  and  $P_n$  are small and have been so for an extended period of time. The idle state corresponds to both the near-end and far-end talkers being silent.

#### 6.4.2 Summary of Requirements on the Echo Canceler

Being a DS1 or E1 device, an echo canceler has several requirements to satisfy that have little or nothing to do with echo cancelation. These are not addressed here. We shall consider only those that pertain to the canceler on a per-channel basis. Thus for all intent and purposes we could consider a single channel only, the requirements being the same for all 24/30 channels. These channels are completely independent and care must be taken in an actual implementation that sharing resources does not compromise the operation of any individual channel.

A complete set of requirements is provided in CCITT Recommendation G.165 [9]. Several network providers have developed their own requirements but these are based on G.165 with variations, if necessary, to reflect the provider's networking philosophy. We shall discuss some of the requirements in detail, those that provide some indication of the signal processing needs and constraints, and not dwell much on the others.

The requirements are described in the form of experiments that can be performed in a laboratory environment. They presume that the operator has some control on the echo canceler. These controls are:

- a) **Clear.** The coefficients of the filter are set to zero.
- b) **Freeze.** The coefficients are held at the present value and not updated.
- c) **Adapt.** Allow the adaptation to resume.
- d) **Disable NLP.** Remove the NLP from the circuit path. Equivalent to disabling the echo suppressor part of the canceler. The echo return loss enhancement is then just that provided by the adaptive filter.
- e) **Enable NLP.** Allow the NLP to perform normally.

#### 6.4.2.1 Echo Return Loss Enhancement Requirement and Compliance Testing

The echo return loss enhancement that can be achieved with an adaptive filter depends on various factors such as, for example, the nature of the signal  $\{x(n)\}$  (which we called the reference signal in Section 6.3) in terms of power and spectral content. The enhancement is also influenced by the **ERL** itself, that which the hybrid provides, power of the near-end signal, impulse response, and so on. To set an appropriate baseline, the requirements are provided using a hypothetical case, one that might never occur in practice, but that can be constructed in a laboratory environment.

Consider the scheme shown in Fig. 6.17, which represents a single channel. The equipment that performs the DS1/E1 multiplexing/demultiplexing is not indicated in the figure. A signal generator is used to provide  $\{x(n)\}$ , which is a white noise signal (8 kHz sampling rate,  $\mu$ -law/A-law encoded) of power that can be varied over a range from  $-10 \text{ dBm}_0$  to  $-30 \text{ dBm}_0$ . An echo path is created that can provide 6+ dB of **ERL** and care is taken to ensure that the effective impulse response of the echo path introduced is not longer than the length of the adaptive filter.

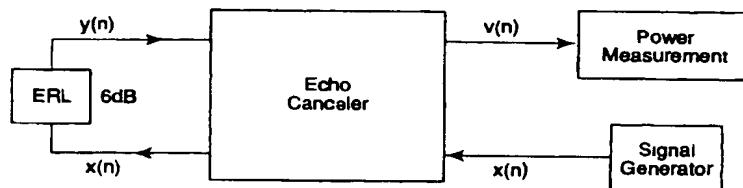


Fig. 6.17  
Test setup for quantifying echo canceler performance

With the **NLP** disabled and the adaptive filter cleared, we expect the power reading to be exactly  $X$  dB below the power of the reference signal  $\{x(n)\}$ , where  $X$  is the **ERL** provided in the tail circuit. With the **NLP** held disabled, the transmit power, the power of  $\{v(n)\}$  is measured for different choices of reference power and the **ERLE** thus computed. Denoting the powers of reference and transmit signals by  $P_x$  and  $P_v$  (in  $\text{dBm}_0$ ), respectively, the **ERLE** is given by